JTCG/ME: Target Studies and Fragment Penetration

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August 16, 2002

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Abstract

The following report describes how a catalogue of foreign targets (red targets) was created for general informational purposes. This report also describes how FATEPEN's effectiveness at predicting the penetration of small right circular cylinders through steel and aluminum plates was tested. FATEPEN's predictions of the residual mass and residual velocity of the right circular cylinders were compared to the residual mass and residual velocity recorded from actual firings. Data analysis was performed and conclusions were made. These efforts showed that FATEPEN was inaccurate at predicting small fragment penetration. Both projects supported ARL research and the triservice Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME).

Introduction

The research on red targets was done to provide a source of general information for quick reference on the targets of interest for ballistic survivability/vulnerability/lethality analysis. A catalogue was created containing the list of the targets and articles containing the basic information on each target and its variants.

The research performed on the program FATEPEN was used to decide whether or not FATEPEN was accurate at predicting the penetration of small steel fragments against various materials. The equations used in FATEPEN did not take into consideration small steel fragments. Therefore this area had to be validated.

In order to do a comparison, the test parameters observed in live shots that had already been taken and recorded were entered into FATEPEN, and the predictions for residual mass and residual velocity of the penetrators from FATEPEN were compared to actual results. Statistical analysis was used to compare the two bodies of results, and a conclusion on the accuracy of the program was reached from the results of this analysis. The conclusion on the accuracy of FATEPEN was used to advise JTCG/ME on whether or not they should use FATEPEN for predicting the penetration of small steel fragments on various targets. ARL is currently using THOR equations to predict fragment penetration.

Red Targets

ARL has a list of red targets that they are currently examining. A catalogue of information on these red targets needed to be created to serve as a convenient source of basic information. The catalogue was to be made up of articles about the red targets. These articles were found on the Internet. Most of the articles were found at the Jane's website (http://online.janes.com/), but some were found at The Federation of American Scientists website (http://www.fas.org/) along with various other sites. Once the articles were found, two copies of each were printed out and put into two binders.

The articles were then organized in the binders so that they would be easy to find. They were put into sections according to target type (i.e., Truck, Tank, Artillery,…). Then a list was created and placed at the beginning of each binder, which listed all the targets in the order that they appeared, so that they could quickly be located (see Appendix A). The catalogue has since been used on several occasions. It was used by a few workers to find quick information on a red target that they were working on at the time. It was also used for quick reference to foreign systems at a JTCG/ME Vulnerability Working Group meeting.

After the catalogue of information on the red targets was created, budget requests for doing ballistic survivability/vulnerability/lethality analyses on select red targets in FY03 were developed. A spreadsheet, which had the various projects that needed funding for FY03, was updated to display the amount of funding requested for each project.

FATEPEN Fragment Penetration

The most important task performed was validating FATEPEN's effectiveness in predicting the penetration of small steel fragments against plates of armor. FATEPEN is a computer program that is used to predict the penetration of fragments, long rods, or projectiles against various target materials. It represents a fragment with one of several geometric shapes that can be selected. These shapes include parallelepiped, cylinder, sphere, tapered/truncated cylinder, and armor piercing projectile. FATEPEN computes the residual velocity and residual mass of the fragment, along with many other outputs.

The data from a series of test shots of right circular cylinders (RCCs) was supplied so that the same shots could be run with FATEPEN. Then the results of FATEPEN and the actual shots could be compared. The data provided was contained in a spreadsheet that consisted of two tabs. The first looked at 546 shots against Aluminum 2024-T3 plates, and the second looked at 431 shots against mild steel plates. In addition, there were three groups of shots each tab. These three groups consisted of three test programs: the Holloway-Danish shots, Phase I shots, and Phase II shots. The data columns that were shown for each shot were the shot number, thickness of the target, obliquity angle, presented area of the fragment, length over diameter ratio of the fragment, striking mass and striking velocity of the fragment, residual mass and residual velocity of the fragment, and any notes on the presented area or residual mass of the fragment (see Appendix B).

To perform an analysis, the spreadsheet data was carefully reviewed for accuracy and units of measure were converted. First, all of the data was in metric units, but it needed to be in customary units to be put into the FATEPEN program. Research was done online to find the conversion factors necessary to transform the spreadsheet from metric to customary units. In addition, any values that were less than one in the length over diameter ratio column had been turned into a date instead of a decimal or fraction. A version of the data without the length of diameter fault was found, and the correct values were put into the spreadsheet. A new spreadsheet was created to operate FATEPEN.

After the data had been corrected, it was decided that additional data could be added to the spreadsheet for a more complete analysis. Some of the fragments that had come off of the RCCs from the Phase II data had been collected and weighed, along with any fragments that had come off of the plates. This allowed additional columns to be added to the spreadsheet for the residual mass.

After this task had been completed, it was determined that the Holloway-Danish data was inaccurate. This data was removed from the spreadsheet so that it would not interfere with the results. Some of the data from Phase I and Phase II was also determined to be too unspecific, because it stated the residual velocity as “perf” (perforated the plate) or “nonperf” (did not perforate the plate), instead of giving a numerical value. All data that was determined to be inaccurate or unspecific was removed from the spreadsheet to prevent it from disrupting the accuracy of the comparison between FATEPEN’s results and the actual results (see Appendix C). This lowered the number of shots against Aluminum 2024-T3 plates to 216 and lowered the number of shots against Mild Steel plates to 139.

Using The FATEPEN Code

After the data had been reformatted and expanded, and all inaccurate or unspecific data had been removed, it was ready to be entered into FATEPEN. The first step was to access the main menu of the program and then select the Penetrator Parameters option inside the Edit Parameters Box (see Appendix E). This brought up a new screen where the parameters of the penetrator could be defined for the shot that was being run (see Appendix F). From here the Cylinder option needed to be selected, since the actual tests used right circular cylinders for all shots. After this was done, the weight and the length over diameter ratio could be set using the data from the spreadsheet. The dimensions of the RCC had to be calculated, since they were not provided in the spreadsheet data. To perform this computation, the Compute option needed to be selected on the tool bar. From there the Dimensions from Mass option would be selected and FATEPEN would calculate the dimensions using the shape, weight, and length over diameter ratio. The next step was to select a Presented Area, and after this was done, FATEPEN would automatically set the Yaw Angle Specification.

Occasionally, the entered presented area value could result in two different Yaw Angle Specifications, in which case a window would come up asking the user to choose between the possible Yaw Angle Specifications. Finally, the angle at which the penetrator struck the plate could be entered. Then the program could be returned to the Main Menu by selecting the Accept option from the Tool Bar.

Once returned to the main menu, the Target Parameters button would be selected from the Edit Parameters box (see Appendix G). From this window the thickness, material, and Brinell Hardness of the target could be set. The first step was to make sure there was only one plate. Extra plates could be deleted by selecting the Delete Plate Element button in the Edit Function Selection box and then by clicking on the Accept Delete button (displayed in Appendix G as Accept Append). Given there was only one plate, the type of material of the plate, the Brinell hardness of that material, and its thickness could all be entered into the white boxes on the bottom half of the screen labeled material, hardness, and thickness. Then the Edit Plate Element option could be selected in the Edit Function Selection box, and the Accept Edit button (displayed in appendix as Accept Append) could be selected. Once this was completed the program could be returned to the Main Menu screen by choosing the Accept option on the Tool Bar.

Once the Penetrator Parameters and Target Parameters had been set, the Run FATEPEN button could be selected (see Appendix H). This would bring up the Execution Options Menu. From this menu the impact velocity of the penetrator could be set by entering it into the two white boxes labeled Starting Velocity and End Velocity.

Now that all the data had been entered into the program, it was ready to be run. This could be done by selecting the Run option on the Tool Bar. Because the shots were organized into groups with the same penetrator parameters and target parameters, many shots could be run in succession where the only piece of data that needed to be changed was the impact velocity. This allowed for several shots to be run in a short period of time, and greatly quickened the process.

After a group of shots had been run, the results could be viewed by going to the Main Menu Screen and selecting the Damage button in the Results section of the View Parameters and Results box. From here they were put into a new spreadsheet, which compared the results that FATEPEN obtained for the residual masses and velocities of the penetrators to the results of the actual tests for residual masses and velocities of the penetrators (see Appendix D).

Exploratory Data Analysis

The data analysis spreadsheet had two tabs, one for shots against Mild Steel plates and one for shots against Aluminum 2024-T3 plates. Each tab was divided into three sections. The first section displayed the results that FATEPEN produced. It had columns for the shot number and residual velocity, and it also had three residual mass columns to record the RCC and any fragments that had broken off. The second section looked at the results from the test shots and contained the same columns as the first section. The third section compared the first two sections by looking at the percent differences in residual mass and velocity. The first column in the third section looked at the percent of difference between FATEPEN's residual velocities and the actual residual velocities. The second column displayed the percent difference between the sum of the residual masses that FATEPEN produced and the sum of the residual masses that the real tests produced. This was later modified to compare only the masses of the main penetrators.

The desired result was for FATEPEN to predict data within ten percent of the data from the actual shots. After looking at the spreadsheet that compared the final results, there were some initial conclusions that could be made about FATEPEN's accuracy. FATEPEN almost always predicted the residual velocity of the penetrator to be much too high against both Mild Steel and Aluminum 2024-T3 targets. It was occasionally within the desired range of ten percent, but it was usually off by at least fifty percent. A possible explanation for this was that FATEPEN took the velocity of the leading edge of the particle cloud behind the plate and the velocity of the penetrator behind the plate and averaged them instead of just taking the velocity of the penetrator. This meant that if debris from the plate was moving faster than the penetrator, the debris would be recorded instead of the penetrator, causing the residual velocity to be too high, which it consistently was in FATEPEN's predictions. It was then reported that the leading edge of the debris cloud was also measured for the residual velocity in the live shots, which disproved the possible explanation for FATEPEN's residual velocity being too high.

The one group of shots that FATEPEN did predict accurately for residual velocity was the AL-2 group of shots against Aluminun 2024-T3 plates (see Appendix D). The original parameters of the AL-2 data were examined. It was noticed that the AL-2 shots were head on, had high length over diameter ratios, and were against thin plates. Other groups of shots with similar parameters were examined to see if they were more accurate than the rest of FATEPEN's results, but no pattern was observed. After this further examination of the data, FATEPEN's accuracy for the residual velocity of the AL-2 series was determined to be inexplicable.

The results for residual masses for both the shots against Aluminum 2024-T3 plates and the shots against Mild Steel plates were found to be much more accurate than the results for residual velocities. FATEPEN's outputs for the residual masses of shots against Aluminum 2024-T3 plates were extremely accurate. Almost all of the results FATEPEN produced were within ten percent of the actual results, and most of them were even within five percent. The output that FATEPEN produced for residual masses of the penetrators against Mild Steel plates was fairly accurate, but most of it did not fall within the desired range of ten percent. The only data that was sufficiently accurate was the data that FATEPEN produced for residual masses against Aluminum 2024-T3 plates.

Statistical Analysis

After the spreadsheets had been completed and the data had been looked over, statistical analysis needed to be performed. In order to make the analyses more accurate, some outliers were removed from the data set. Then t-Tests were run on the data. The initial t-Tests produced data that was not very useful, so new tests were suggested at a meeting and agreed upon. These tests would show how much of FATEPEN's data fell within a given range of accuracy. Mr. Alex Breuer (ARL) ran the tests needed to produce these results. The results for the residual masses of the penetrators against the Aluminum 2024-T3 plates showed that FATEPEN was within five percent of the actual results approximately eighty-four percent of the time, that it was within ten percent of the results approximately ninety percent of the time, and that it was within fifteen percent of the actual results approximately ninety-two percent of the time. The results for the residual velocities of the penetrators against the Aluminum 2024-T3 plates showed that FATEPEN was within five percent of the actual results approximately five percent of the time, that it was within ten percent of the actual results ten percent of the time, that it was within fifteen percent of the results seventeen percent of the time, that it was within twenty five percent of the results thirty percent of the time, and that it was within fifty percent of the results approximately forty nine percent of the time.

The work on FATEPEN was done to help ARL and JTCG/ME identify when to use FATEPEN and when to use THOR, a similar program, to run shots of small steel fragments against various targets. The Army is looking into using FATEPEN for small steel fragment penetration in lieu of THOR.

Summary

The Red Targets research was done to create an easily accessible database on foreign systems. It was used at the JTCG/ME Vulnerability Working Group for quick reference to Red Targets. The research done on FATEPEN was done to decide if FATEPEN was sufficiently accurate at predicting small steel fragment penetration. This was done to advise JTCG/ME on whether or not to use FATEPEN instead of THOR for predicting small steel fragment penetration. It was discovered that FATEPEN was accurate at predicting residual mass but inaccurate at predicting residual velocity. The FATEPEN developer has an improved version of FATEPEN for small fragments. The new software version will be delivered in a month and comparisons will be re-run.

Knowledge Gained

The SEAP Program was a great experience. It provided the opportunity to see how the real world works and to see what it is like to have a full time job. It also was a good way to develop better researching techniques. An example of this is the Red Targets research, which required a great deal of research to be done over the Internet. Additionally, it provided the opportunity to use the basic commands and functions of the UNIX operating system. This operating system is an important part of the working environment, and being part of the SEAP programmed allowed for a good deal of exposure to it. Furthermore, the SEAP program presented the opportunity to learn a great deal about the various fields of math and science. By talking to and observing co-workers who know a great deal about a particular field, a great deal can be learned. Just by participating in work, that relates to a certain field, a great deal of knowledge about that field can be gained.

Acknowledgements

Special thanks to:

Wendy Winner for being a great mentor,
Alex Breuer for working with me on the FATEPEN project,
and the entire Aircraft and Light Armor Systems Branch for making my working experience beneficial and enjoyable.

Appendix A – List of Red Targets

Classification	Target Name
Trucks	Ural-375D (6x6) GAZ-66 (4x4) ZIL-157 (6x6) ZIL-131 (6x6)
Air Defense	SA-11 GADFLY, 9K37M1 BUK-1M SA-12A Gladiator and SA-12B GIANT, S-300V, HQ-18 SA-6 Gainful, ZRK-SD Kub 3M9 2S6M Tunguska Tunguska M1 (2S6M1) M1978, M1989 Self-Propelled Gun M1992 Self-Propelled Gun 37-mm SA-2 GUIDELINE, V-75, HQ-1/HQ-2, Tayir as Sabah SA-4 GANEF SA-8 GECKO, 9K33M3 Osa-AKM Oerlikon Contraves Skyguard
Artillery (Field Artillery)	9K51 BM-21 Gras, 9A51 Prima, Sakr-18, 122-mm MRL Splav 300-mm BM 9A52, Smerch multiple rocket system 2S19 MSTA-S 152-mm Self-Propelled Howitzer 2S3 M-1973 Akatsiya 152-mm Self-Propelled Gun-Howitzer 2S1 M-1974 Gvodzika 122-mm Self-Propelled Howitzer 2S7 203-mm Self-Propelled Gun 2S9 Anona 120mm SPH/Mortar D-20/M-55, Type 66 152-mm Towed Gun-Howitzer D-30 2A18M 122-mm Towed Howitzer R-11/SS-1B SCUD-A, R-300 9K72 Elbrus/SS-1C SCUD-B 9A52-2 BM-30 Smerch 300-mm MRL Al Hussein/al-Husayn/Al Hijarah Al Jaleel 120-mm mortar Splav 220-mm BM 9P140 Dana ZTS 152-mm Self-Propelled Gun-Howitzer M1987 170-mm Self-Propelled Gun Koksan M1991 240-mm MRL M1992 Self-Propelled Gun 130-mm Tula KBP 96K6 Pantzyr-S1 Self-Propelled SA-10 Grumble, SA-N-6 Grumble, S-300PMU, HQ-10/15 ZSU-23-4 Shilka 23-mm ZSU-57-2, Type-80 9P140 Uragan 220-mm MRL
Tracked IFV (Infantry)	BMP-1 BMP-2 BMP-3 BMP-1976, 2A63 152-mm Artillery Command and Reconnaisance Vehicle (ACRV)

	MT-LB BMD-1 BMD-3
Wheeled APC/IFV (Infantry)	BRDM-2, BTR-40P-2 BTR-80 BTR-60 BTR-90 BTR-50P BTR-70 M-9, CSS-6, DF-15 Cadillac Gage LAV-150S, LAV-300 BOV-3 triple 20-mm, BOV-30 twin 30-mm
Tanks (Armor)	Type 96 (8x8) Type 98 MBT PT-76 T54, T55 T62 T64 T72 T80 T90 PT-91 MBT Twardy
Aviation	ATE Vulture Ka-50 Hokum, Ka-52 Hokum B SA 341 Gazelle, SA 342 Gazelle Mi-28 Havoc Mi-24 Hind, Mi-25 Hind D, Mi-35 Hind E Mi-8 Hip Mi-2 Hoplite Z-9, AS 565 Panther, SA 360 Dauphin 2 MD 500, MD 300 Agusta Su-25 Frogfoot Grach, Su-39 Frogfoot Eurocopter EC 120, CATIC, ST Aero
Commo Vehicles	C2V, M4 Command and Control Vehicle SNAR-10, Big Fred Radar System GAZ-66 (4x4) R-414-5 Radio Relay Station R-419A Radio Relay Station S-60, Type 59 57-mm SA-10/20 Grumble SA-15 Gauntlet, SA-N-9, 9K331 Tor, HQ-17 SA-6 Gainful, ZRK-SD Kub 3M9 SA-17 Grizzly/Buk-M1-2, SA-N-12 Grizzly/Yezh, HQ-16
Other	STYX SS-N-2
Battlefield Surv. Radar	Type 704, BL904

Appendix B – Sample of the Data Collected from Live Shots

Shot No.	Target Thickness (mm)	Obl (deg)	Fragment Presented Area* (mm^2)	L/D	V_s (mps)	M_s (grams)	V_r (mps)	M_r (grams)	Notes
AL1-1	3.175	0	5.9102	2	603.01	0.2592	370.236	0.2541	
AL1-3	3.175	0	5.9102	2	581.152	0.2592	perf	------	
AL1-7	3.175	0	5.9102	2	466.945	0.2592	267.232	0.2541	
AL1-8	3.175	0	5.9102	2	543.393	0.2592	322.785	------	
AL1-9	3.175	0	5.9102	2	486.773	0.2592	perf	------	
AL2-2	1.588	0	5.9102	2	350.197	0.2592	nonperf	------	
AL2-3	1.588	0	5.9102	2	310.872	0.2592	241.062	0.2541	
AL2-4	1.588	0	5.9102	2	316.767	0.2592	nonperf	------	
Al2-6	1.588	0	5.9102	2	191.934	0.2592	nonperf	------	
AL2-7	1.588	0	5.9102	2	413.494	0.2592	334.886	0.2592	**
AL2-8	1.588	0	5.9102	2	671.671	0.2592	551.528	0.2566	
AL2-9	1.588	0	5.9102	2	844.586	0.2592	726.275	0.2566	
AL3-1	6.35	0	25.1981	02-Jan	1396.518	0.6481	556.052	0.6286	
AL3-2	6.35	0	25.1981	02-Jan	1211.551	0.6481	393.177	0.2281	
AL3-4	6.35	0	25.1981	02-Jan	608.46	0.6481	nonperf	------	
AL3-5	6.35	0	25.1981	02-Jan	842.066	0.6481	65.457	------	
AL3-6	6.35	0	25.1981	02-Jan	785.706	0.6481	nonperf	------	
AL3-7	6.35	0	25.1981	02-Jan	816.399	0.6481	nonperf	------	
AL3-9	6.35	0	25.1981	02-Jan	817.386	0.6481	nonperf	------	
AL3-10	6.35	0	25.1981	02-Jan	823.31	0.6481	90.632	0.6455	
AL3-11	6.35	0	25.1981	02-Jan	824.297	0.6481	105.738	0.6442	
AL3-12	6.35	0	25.1981	02-Jan	825.284	0.6481	30.211	------	
AL3A-1	3.24	0	25.1981	04-Jan	908.469	0.324	nonperf	------	
AL3A-4	3.24	0	25.1981	04-Jan	1100.749	0.324	nonperf	------	
AL3A-6	3.24	0	25.1981	04-Jan	1159.247	0.324	nonperf	------	
AL3A-7	3.24	0	25.1981	04-Jan	1174.847	0.324	nonperf	------	
AL3A-9	3.24	0	25.1981	04-Jan	1183.622	0.324	nonperf	------	
AL3A-10	3.24	0	25.1981	04-Jan	1231.396	0.324	nonperf	------	
AL3A-11	3.24	0	25.1981	04-Jan	1204.096	0.324	nonperf	------	

**** - residual mass is greater than or equal to the striking mass**

Appendix C – Sample of Reformatted Data with Additional Information

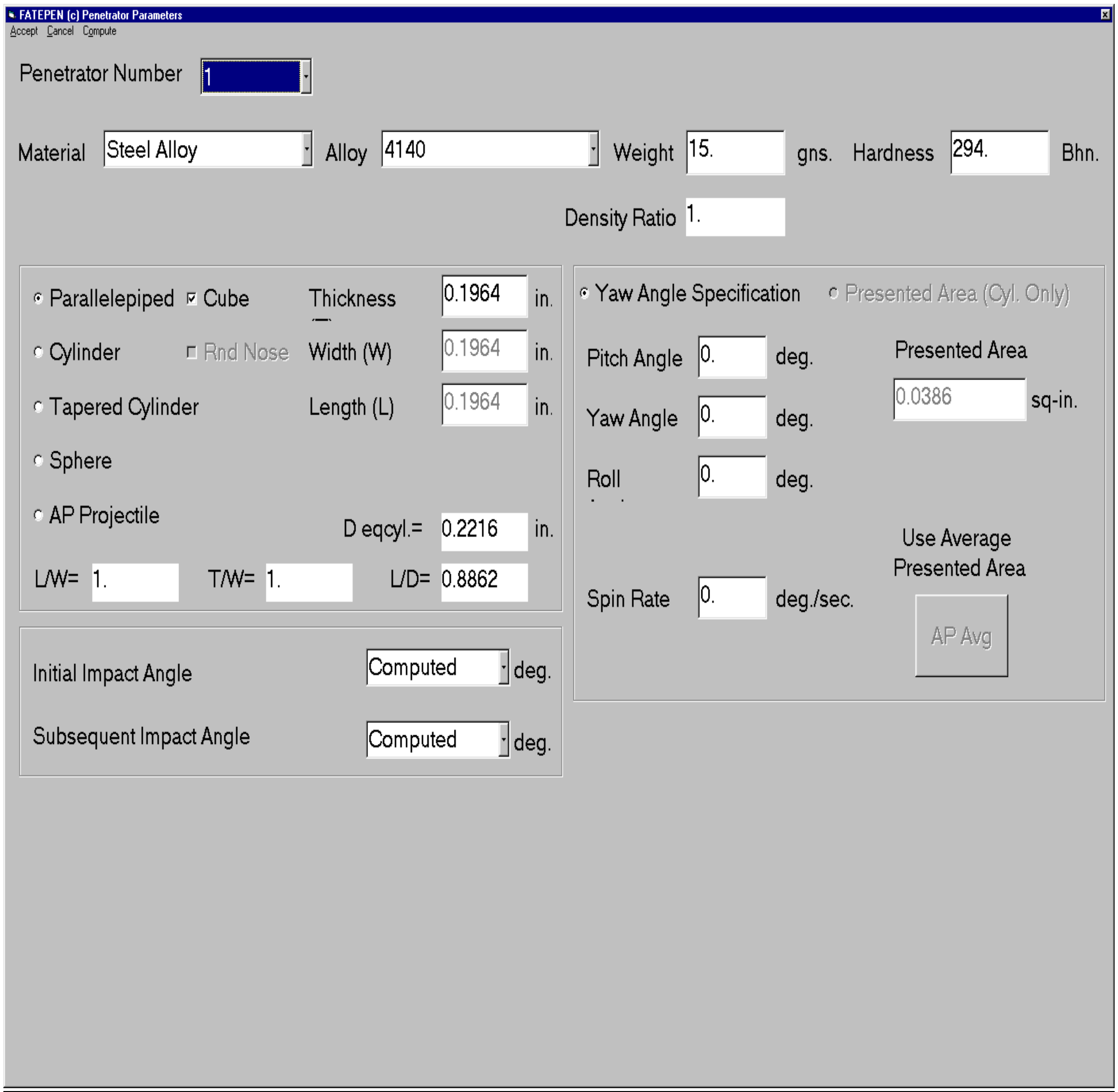
	Shot No.	Target Thickness (in)	Obl (deg)	Fragment Presented Area* (in^2)	L/D	V_s (ft/s)	M_s (grains)	V_r (ft/s)	M_{r1} (grains)	M_{r2} (grains)	Notes	number of recorded fragments	number of plugs	weight of plug 1 (grains)
61	AL1-1	0.125	0	0.0091608	2	1978.3793	4.0000673	1214.685	3.9213623			1	1	0.62
62	AL1-7	0.125	0	0.0091608	2	1531.9718	4.0000673	876.74541	3.9213623			1	1	0.76
63	AL1-8	0.125	0	0.0091608	2	1782.7854	4.0000673	1059.0059	------					
64	AL2-3	0.0625197	0	0.0091608	2	1019.9213	4.0000673	790.88583	3.9213623			1	1	0.36
65	AL2-7	0.0625197	0	0.0091608	2	1356.6076	4.0000673	1098.7073	4.0000673		**	1	1	0.38
66	AL2-8	0.0625197	0	0.0091608	2	2203.645	4.0000673	1809.4751	3.9599432			1	0	
67	AL2-9	0.0625197	0	0.0091608	2	2770.9514	4.0000673	2382.792	3.9599432			1	0	
68	AL3-1	0.25	0	0.0390571	1/2	4581.752	10.001711	1824.3176	9.7007805			1	2	1.06
69	AL3-2	0.25	0	0.0390571	1/2	3974.9049	10.001711	1289.9508	3.5201209			0	2	3.52
70	AL3-5	0.25	0	0.0390571	1/2	2762.6837	10.001711	214.75394	------					
71	AL3-10	0.25	0	0.0390571	1/2	2701.1483	10.001711	297.34908	9.9615873			1	0	
72	AL3-11	0.25	0	0.0390571	1/2	2704.3865	10.001711	346.90945	9.9415253			1	0	
73	AL3-12	0.25	0	0.0390571	1/2	2707.6247	10.001711	99.117454	------					

Appendix D – Sample of FATEPEN Results Compared to Actual Results

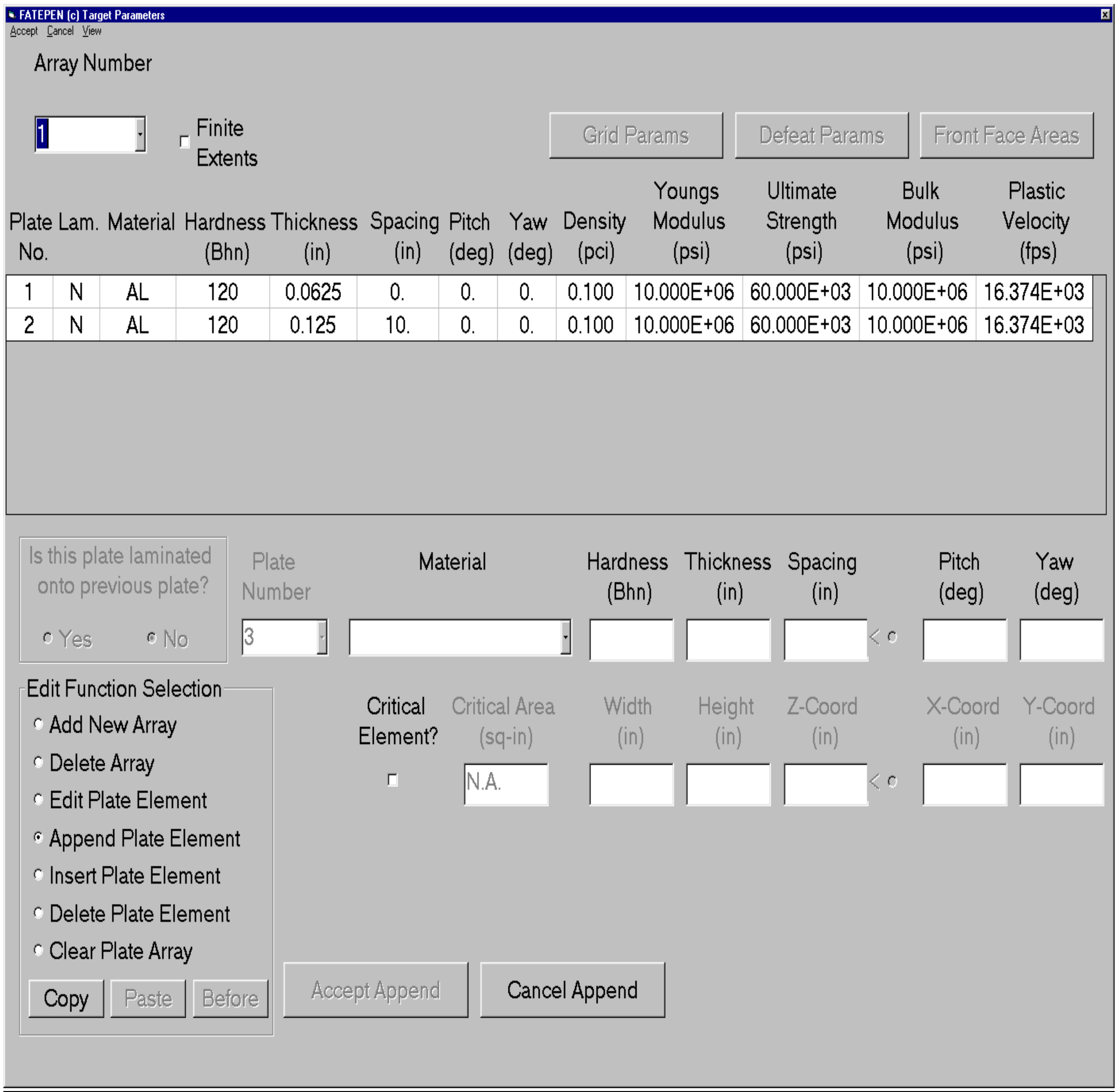
FATEPEN					Actual Results						
Shot Number	V_R (ft/s)	M_{R1} (grains)	M_{R2} (grains)	M_{R3} (grains)	Shot Number	V_R (ft/s)	M_{R1} (grains)	M_{R2} (grains)	M_{R3} (grains)	Percent of Difference in V_R	Percent of Difference in M_R
AL1-1	1506.22	3.996	0	0	AL1-1	1214.685	3.9213623	0	0	24.00	1.90
AL1-7	1035.24	3.9968	0	0	AL1-7	876.74541	3.9213623	0	0	18.08	1.92
AL1-8	1307.16	3.9964	0	0	AL1-8	1059.0059	------	0	0	23.43	------
AL2-3	812.73	4.0001	0	0	AL2-3	790.88583	3.9213623	0	0	2.76	2.01
AL2-7	1162.56	4.0001	0	0	AL2-7	1098.7073	4.0000673	0	0	5.81	0.00
AL2-8	1987.86	3.9817	0	0	AL2-8	1809.4751	3.9599432	0	0	9.86	0.55
AL2-9	2520.04	3.8381	0	0	AL2-9	2382.792	3.9599432	0	0	5.76	-3.08
AL3-1	2829.52	9.6677	0	0	AL3-1	1824.3176	9.7007805	0	0	55.10	-0.34
AL3-2	2348.24	9.7457	0	0	AL3-2	1289.9508	3.5291209	0	0	82.04	176.15
AL3-5	1277.78	10.0017	0	0	AL3-5	214.75394	------	0	0	495.00	------
AL3-10	1229.58	10.0017	0	0	AL3-10	297.34908	9.9615873	0	0	313.51	0.40
AL3-11	1231.97	10.0017	0	0	AL3-11	346.90945	9.9415253	0	0	255.13	0.61
AL3-12	1234.36	10.0017	0	0	AL3-12	99.117454	------	0	0	1145.35	------

Appendix E – FATEPEN Main Menu

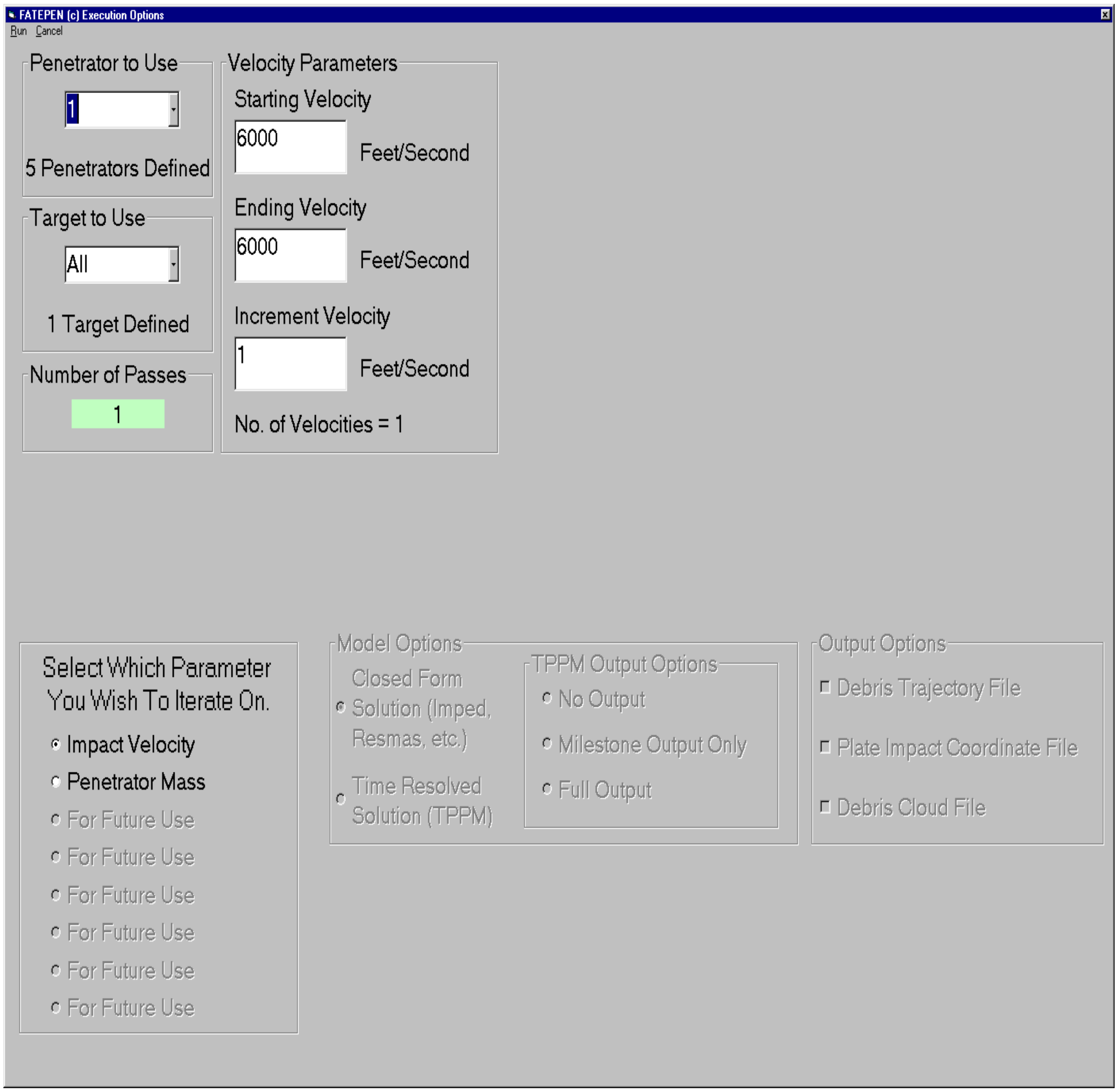
Appendix F – Edit Penetrator Parameters Menu



Appendix G – Edit Target Parameters Menu



Appendix H – Execution Options Menu



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